BAA 05-11: Optical Arbitrary Waveform Generation

Proposer Information Pamphlet

This pamphlet provides further information on Optical Arbitrary Waveform Generation (Optical AWG), the submission, evaluation, and funding processes, proposal and proposal abstract formats, and other general information.

The Defense Sciences Office (DSO) and the Microsystems Technology Office (MTO) in the Defense Advanced Research Projects Agency (DARPA) are soliciting innovative research proposals to advance science and technology of optical arbitrary waveform generation and its applications. The ultimate vision for the Optical Arbitrary Waveform Generator (AWG) is to demonstrate a compact, robust, practical, stable octave-spanning optical oscillator, and to demonstrate the ability to independently encode/decode (both via amplitude and phase modulation) all individual frequency components of such an octave-spanning oscillator with an update rate approaching the mode-locked repetition rate. This would provide an unprecedented level of performance for optical systems, and enable numerous high level applications, including sub-diffraction-limited imaging and ultra-wideband optical communications.

Proposed research should investigate innovative approaches that enable revolutionary advances in science, devices, or systems. Specifically excluded is research that primarily results in incremental or evolutionary improvements to the existing state of practice.

BACKGROUND AND DESCRIPTION

Modern-day pulsed radiofrequency and microwave transmitters exploit large fractional bandwidths (defined as the ratio of the bandwidth of the system to its carrier frequency, which approaches unity in RF systems) to enable a tremendous variety of pulse formats for efficient encoding of information. This bandwidth is used at the system level to improve channel capacity and isolation, signal reception, or decrease noise sensitivity, for example. A further demonstration of the ease with which waveform manipulation is accomplished has been the development of commercial RF arbitrary waveform generators (AWGs) with fractional bandwidths greater than 50% at 2 GHz. However, fractional bandwidth that is exploited in current systems decreases with increasing carrier frequency until it is approximately 10^{-3} in systems utilizing the 1.5 micron communications band.

Despite being an example of the state of the art, optical communications systems have extremely limited fractional bandwidths when compared to, for example, wireless communications standards such as 802.11b. The ultimate bandwidth limitations occur in optical systems due to such factors as frequency stability of the laser oscillator; selection of information coding scheme; passive optical element performance; modulator and detector efficiency, speed, and bandwidth; and nonlinear effects due to

the transmission medium. Radical new approaches are required to bring useable fractional bandwidth in optical systems close to unity.

Recent advances in ultra-fast optics provide a roadmap for improving the fractional bandwidth of optical systems by orders of magnitude. The core technology components of the envisioned system are a mode-locked and frequency-stabilized, octave-spanning optical frequency comb functioning as a stable local oscillator; an encoder (or pulse shaper) that would modulate multiple frequency components; and a decoder / receiver capable of extracting the encoded information. The ultimate vision for the Optical AWG is to demonstrate a compact, robust, practical, stable octave-spanning optical oscillator, and to demonstrate the ability to independently encode/decode (both via amplitude and phase modulation) all individual frequency components of such an octave-spanning oscillator with an update rate approaching the mode-locked repetition rate. This would provide an unprecedented level of performance in optical systems, and enable numerous high-impact applications.

PROGRAM OBJECTIVES

To make this vision a reality, the Optical AWG Program has two specific objectives that define our areas of interest: 1) to demonstrate technology for producing (and detecting) arbitrary optical waveforms with fractional bandwidths approaching 10%; and 2) to demonstrate system applications of Optical AWGs that are of high military interest, including (but not limited to) those that take inspiration from systems utilizing complex RF waveforms as a means of improving system performance.

It is expected that this research will be conducted in three phases (specified below), with definitive near-, mid- and far-term milestones proposed over a several year period in order to provide measurable metrics for monitoring success toward overall program goals. In order to minimize unnecessary effort in proposal preparation and review, proposers are strongly encouraged (but are not required) to discuss their ideas with the technical points of contact prior to submitting a proposal. The following sections provide background information about the research topic as well as detailed instructions for submitting proposals to the Optical AWG program.

AREAS OF INTEREST

This announcement is a call for proposals describing research to demonstrate three core technology components of an optical arbitrary waveform generation and detection system. Additionally, we request proposals to demonstrate a specific system application, chosen by the proposer, of an Optical Arbitrary Waveform Generator that is of high military interest.

I. Optical AWG Technology Development

The first major interest of the Optical AWG program is the development and demonstration of a high-fractional bandwidth Optical Arbitrary Waveform Generator. This area of interest has three sub-tasks:

A. COMPACT, STABLE, HIGH BANDWIDTH OPTICAL OSCILLATOR – Stabilized, octave-spanning optical frequency combs [Nature **416**, 233 (2002) and references therein] have revolutionized the field of frequency metrology by providing unprecedented resolution and precision. The output of an octave-spanning comb is an extremely short (few femtoseconds) optical pulse that is composed of many (10^4 to 10^6) coherent frequency components, spaced by the repetition rate of the laser and aligned to an absolute frequency grid. This is accomplished by locking a high frequency component to twice the frequency of the component an octave below, a technique known as carrier-envelope phase locking. The goal for this sub-task is to demonstrate an octave-spanning optical frequency comb suitable for *non-laboratory* use. Proposals should clearly quantify the attributes of the proposed oscillator. These should include, but are not limited to: frequency accuracy, frequency stability, absolute element linewidth, frequency drift, center wavelength of operation, repetition rate, phase stability, and average power.

Proposals will be evaluated based on the reasonable expectation of exceeding the above goals by as much as possible in a device capable of operation in a non-laboratory environment. Proposals should clearly define quantitative performance milestones to be demonstrated two months prior to the completion of each program phase.

B. ENCODER/DECODER – Optical modulators have long been used with continuous-wave (CW) lasers for both amplitude and frequency modulation; however such methods are limited in overall bandwidth by the material properties of the modulators. Waveform generation from mode-locked short-pulse lasers has progressed utilizing more complicated pulse shaping schemes [Rev. Sci. Instr. **71**, 1929 (2000) and references therein] that have the potential for extremely large serial bandwidth. Essentially, a pulse shaper disperses the spectral components of an incoming pulse, modulates a portion of the overall spectrum via an encoding element, and recombines the modulated spectrum. Pulse shapers have been demonstrated to operate via both spatial and temporal dispersion of the incoming pulse spectrum; however, nearly all techniques pursued to date suffer from common limitations: poor spectral resolution of the encoder elements,

small numbers of effective encoding elements, slow waveform update rates, and limited modulation depth. The goal of this sub-task is to match the performance of waveform encoder with the performance of the oscillator to provide: 1. Spectral resolution equivalent to the input comb spacing frequency, 2. Sufficient encoder elements to modulate each spectral component, 3. The capacity for multi-bit modulation depth, and 4. Sufficient agility to alter the encoded waveform uniquely for each input pulse. We are especially interested in modulation architectures that preserve the overall coherence of the frequency components, or at least allow any imprinted phase relationship to be demodulated by a subsequent decoder without need of an additional communication channel. Proposals will be evaluated based on the reasonable expectation of reaching as many of the four goals listed above as possible within the confines of the program timeline. Proposals should clearly outline quantitative performance milestones to be demonstrated two months prior to the completion of each program phase.

C. DETECTOR – Direct detection of ultrashort optical pulses poses a difficult problem. To begin with, few materials have response times faster than a few picoseconds, and further bandwidth limitations are posed by any subsequent optoelectronic components. Detection techniques that have significant bandwidth are often insensitive to phase, making the phase-based encoding techniques common in RF and microwave systems cumbersome to implement in short-pulse optical systems. Finally, detection requirements are highly sensitive to a chosen application; imaging applications levy significantly different, yet arguably no less difficult, demands on the detection sub-systems than do communication applications. The goal of this sub-task is to demonstrate detectors for applications such as: 1. Two dimensional detector arrays for object imaging. We are particularly interested in imaging methods that rely on the production and detection of arbitrary waveforms (such as synthetic aperture or inverse synthetic aperture techniques). 2. Phase sensitive or matched filter detectors that would be sensitive to phase-based encoding schemes. Please note that the above are representative examples, and are not meant to be exclusive areas of interest. We are particularly interested in those detection techniques that would operate at (or near) the bandwidth limit of the arbitrary waveform encoder/decoder. Proposals will be evaluated based on the reasonable expectation of reaching as many of the above goals as possible within the confines of the program timeline. Proposals should clearly outline quantitative performance milestones to be demonstrated two months prior to the completion of each program phase.

II. Demonstration of an Application of Potential Military Interest

In order to speed the development of militarily useful applications of optical arbitrary waveforms, we are seeking innovative proposals that undertake the integration of an envisioned Optical AWG with the characteristics outlined in Area of Interest I-Optical AWG Technology (see above) into system-level demonstrations. In particular, we are interested in proposals that outline the use of optical arbitrary waveform generators built upon carrier-envelope phase stabilized oscillators and extremely advanced pulse shapers (encoders/decoders) as outlined in Area of Interest I. Relevant military applications include, but are clearly not limited to, the following.

SUB-DIFFRACTION-LIMIT IMAGING – Synthetic aperture and inverse synthetic aperture imaging, particularly when utilizing non-impulse coded optical waveforms can provide tremendous resolution to optical systems. Proposals must clearly demonstrate how use of Optical AWG Technology (from Area of Interest I) will lead to significant performance enhancements over existing system designs.

ULTRA-WIDEBAND OPTICAL COMMUNICATIONS – Expected increases in available bandwidth and phase-sensitive detection techniques point to novel possibilities in optical communications. Particular attention will be paid to either those proposals that pursue low-probability-of-intercept (LPI) communications links that avoid sacrificing system bandwidth below proposed 40 GB/sec communications standards, or those that outline multi-channel techniques for long-range communication at both high system bandwidth (>40 GB/sec) and high channel isolation. Proposals must clearly demonstrate how use of Optical AWG Technology (from Area of Interest I) will lead to significant performance enhancements over existing system designs.

HIGH-SPEED ELECTRONIC ARBITRARY WAVEFORM GENERATION – Use of Optical AWG Technology (from Area of Interest I) appears promising as a means to provide high-speed (carrier frequency >60 GHz), high-bandwidth arbitrary waveforms for electronic systems. Particular attention will be paid to systems that align with the above areas of interest (i.e., SAR and communications applications), but a proposal in this area must demonstrate use of optically generated high carrier frequency, high bandwidth arbitrary RF waveforms. Proposals must clearly demonstrate how use of Optical AWG Technology (from Area of Interest I) will lead to significant performance enhancements over existing system designs.

Proposals responding to either area of interest should be composed of an 18-month system design study (Phase I) with a critical design review at 16 months, followed by two 24-month efforts (Phases II and III). Clearly stated, quantitative milestones are required 11 and 22 months into each of these optional phases. Organizations wishing to participate in Phase II or Phase III should include them as an option in their proposal as appropriate. Proposals must clearly demonstrate how use of Optical AWG Technology (from Section I) will lead to significant performance enhancements over existing system designs.

TEAMING ARRANGEMENTS

Proposals Responding to Area of Interest I: We realize that this is a challenging and high-risk program. In order to mitigate risk, we envision supporting multiple, orthogonal approaches to each of the sub-tasks in this area of interest. The formation of teams to address multiple sub-tasks is not necessary to be competitive; however such teams will be considered.

Proposals Responding to Area of Interest II: Teaming is **strongly encouraged** for proposals to demonstrate systems applications of Optical AWG technology. The viability of teaming arrangements, including tasks and measurable milestones for each team member, should be clearly explained in the proposal. Emphasis will be placed on integrated approaches, i.e., integrated teams formed to better address the many different technological and scientific aspects of this program. For example, areas of expertise that might be incorporated into these teams include materials science, laser physics, optics, device physics, systems design, simulation, fabrication, testing and integration, and applications, etc. Teaming between industries, commercial and defense system integrators, federal and national laboratories, and universities with complementary areas of expertise is strongly encouraged. It is anticipated that any team would be led by an individual/organization with significant systems experience. It is recognized that this is a challenging and high-risk program. Proposals addressing different applications of the Optical AWG technology are encouraged to mitigate risk.

A website http://awg.walcoff.com will be established to facilitate teaming between interested parties. Interested parties may post on the web site the points of contact (POC), their address, telephone and fax numbers, e-mail information and any non-proprietary information about their areas of expertise and interest that may help in forming the teams. Specific information content, communications, networking, and team formation are the sole responsibilities of the participants. Neither DARPA nor the Department of Defense (DoD) endorses the destination website or the information and organizations contained therein, nor does DARPA or the DoD exercise any responsibility at the destination. This website is provided consistent with the stated purpose of this announcement. The web site will also provide answers to frequently posed questions regarding the solicitation.

PROGRAM SCOPE

The Optical Arbitrary Waveform Generation program will consist of an 18 month (Phase I) effort. This will be followed by two subsequent 24 month efforts (Phases II and III). Clearly stated, quantitative milestones are required 11 and 22 months into each of these phases. Organizations wishing to participate in Phase II or Phase III should include them as an option in their proposal as appropriate. We realize that this is a challenging and high-risk program. In order to mitigate risk, multiple awards are anticipated. Cost sharing is not required and is not an evaluation criterion, but is encouraged where there is a reasonable probability of a potential commercial application related to the proposed research and development effort.

Questions concerning the scope of this BAA may be directed to the either of the technical points of contact for this effort: Dr. John R. Lowell, phone: (571) 218-4685, fax: (703) 807-4962, electronic mail: jlowell@darpa.mil; or Dr. Jagdeep Shah, phone: (703) 696-2253, fax: (703) 696-2206, electronic mail: jshah@darpa.mil.

PROPOSAL INFORMATION

In order to minimize unnecessary effort in proposal preparation and review, proposers are strongly encouraged (but are not required) to discuss their ideas with the technical points of contact in advance of submitting a full proposal.

Copies of proposal submissions may contain duplicates of the original cover sheet. Please include e-mail addresses on cover page. Facsimile proposals will not be accepted and institutional brochures, reprints, and videotapes will be ignored. All proprietary material should be clearly marked and will be held in strict confidence. Early submission of proposals is encouraged. Selections can be made at any time during the process. Within approximately ten (10) business days of receipt, DARPA will acknowledge receipt of the submission and assign a control number that should be used in all further correspondence regarding the proposal. If proposals are not submitted electronically, proposers should submit 6 copies of the proposal and an electronic copy of the proposal on a ZIP disk or CD, in .pdf format.

While DARPA does not participate or provide direction in the formation of research teams, in order to facilitate teaming opportunities for interdisciplinary work, DARPA is sponsoring a Teaming Website at the following URL: http://awg.walcoff.com. Investigators can use this site to make others aware of their own capabilities and to identify capabilities they seek in potential teammates. The web site will also provide answers to frequently posed questions regarding the solicitation.

Full proposals will consist of two volumes, Technical and Cost.

Volume I, Technical Proposal, should contain, in a maximum of 50 pages [page limits in brackets, if applicable]:

1. [1p] Cover sheet with the following information (format is left to the proposer):
    A. BAA Number (05-11) and Title (Optical Arbitrary Waveform Generation);
    B. Technical Area of Interest;
    C. Lead Organization submitting proposal;
    D. Type of business, selected among the following categories: "LARGE BUSINESS," "SMALL DISADVANTAGED BUSINESS," "OTHER SMALL BUSINESS," "HBCU," "MI," "OTHER EDUCATIONAL," or "OTHER NONPROFIT,";
    E. Contractor's reference number (if any);
    F. Other team members (if applicable) and type of business for each;
    G. Proposal Title;
    H. Technical point of contact, to include: salutation, first name, last name, street address, city, state, zip code, telephone, fax (if available), and electronic mail address (if available);
    I. Administrative point of contact, to include information as in (H) above;
    J. Award instrument requested, selected among: cost-plus-fixed-fee (CPFF); cost-contract--no fee; cost sharing contract--no fee; or other type of procurement contract (specify), grant, cooperative agreement, or other transaction;
    K. Place(s) and period(s) of performance;
    L. Total proposed cost separated by basic award and option(s) (if any);
    M. Name, address, and telephone number of the offeror's cognizant Defense Contract Management Agency (DCMA) administration office (if known);
    N. Name, address, and telephone number of the offeror's cognizant Defense Contract Audit Agency (DCAA) audit office (if known);
    O. Date proposal was prepared; and
    P. DUNS, TIN, CAGE CODE;
2. [2p] An Executive Summary that clearly and concisely summarizes the following:
    A. Describe the quantitative end-of-program performance goal(s) and the milestones associated with each phase of the development effort. The milestones and performance goals should be listed in a single table (see below for an example table);
    B. Explain how the above goals and milestones compare to what has already been demonstrated;
    C. Describe the unique approaches and technical solutions proposed;
    D. Explain how and to what extent (being as quantitative as possible) the proposed work will benefit the Department of Defense;
3. [12p] A concise section outlining the scientific and technical challenges, unique approaches, and potential anticipated technical solutions to the challenges that will be addressed. This statement should demonstrate that the proposer has a clear understanding of the state-of-the-art; and should provide sufficient technical details so as to permit complete evaluation of the feasibility of the idea;

4. [12p+1 table] A narrative explaining the explicit timelines, milestone achievements, and quantitative metrics by which progress toward the goals can be evaluated. These milestones should reflect an initial period of performance of 18 months with subsequent 24 month periods of performance, as is discussed in the Program Scope section above. Milestones must be associated with demonstrable, quantitative metrics of performance, and should be summarized in a single table. An example table is included as an Excel spreadsheet; proposers may use this example or substitute an equivalent of their design. The milestones and performance goals should be provided for each task as well as the overall program and system application, if appropriate;
5. A management plan that describes how the different members of the team will be harnessed to demonstrate a viable solution to the challenge problem(s);
6. A section describing the relevant prior work, background of key individuals and facilities to be utilized. Please do not attach supporting material (articles, CDs, movies, etc.) to the proposal;
7. [5p] PowerPoint-type slides (i.e., landscape formatted for presentation) that graphically highlight the major aspects of the proposal;
8. If you choose a system-level demonstration other than those listed in this addendum, you must explain why you believe: a) it is equivalent to or exceeds the challenges posed here; b) it is of interest to DoD; and, c) it requires development of new capabilities to produce arbitrary optical waveforms. We are looking for ideas that will generate revolutionary capabilities if the proposed work is completed successfully over the entire period of performance. While distinct goals for the proposal must be identified, the scope of the idea and approach may extend past the performance period;

Again, all quantitative program goals and milestones should be summarized in a table similar to the Excel spreadsheet included as part of the PIP.

Volume II, Cost Proposal, should contain:

1. [1p] Cover sheet with the required information (see cover sheet for Volume I):
2. Detailed cost breakdown, to include:
    A. Total program cost broken down by major cost item (direct labor, subcontracts, materials, travel, other direct costs, overhead charges, etc.);
    B. Itemization of major subcontracts (direct labor, subcontracts, materials, travel, other direct costs, overhead charges, etc.) and equipment purchases;
    C. Where the effort consists of multiple portions that could reasonably be partitioned for purposes of funding (i.e., major research task, program phase), these should be identified as options with separate cost estimates for each;
3. Supporting cost and pricing information with sufficient detail to substantiate the summary cost estimates in (2) above. Include a description of the method used to estimate costs and supporting documentation. *Note*: "cost or pricing data" as defined in FAR Subpart 2.101 shall be required if the offeror's proposal is for a procurement contract award of $550,000 or greater unless the offeror requests an exception from the requirement to submit cost or pricing data. "Cost or pricing data" are not required if the offeror proposes an award instrument other than a procurement contract (e.g., a grant, cooperative agreement, or other transaction). The requirements for submission of "cost or pricing data" are specified in FAR Subpart 15.403-4 (see http://www.arnet.gov/far);

AWARDS AND PROPOSAL EVALUATION

The number of awards will be dependent on the suitability of proposals received and availability of funds. Early submission of proposals is encouraged. **PROPOSALS ARE DUE NO LATER THAN 1600 EST, Tuesday, February 15, 2005.** Full proposals submitted after the due date specified in the BAA will not be considered. The Government reserves the right to select for award all, some, or none of the proposals received and to make awards without discussions. All responsible sources capable of satisfying the Government's needs may submit a proposal which shall be considered by DARPA. Input on technical aspects of the proposals may be solicited by DARPA from non-Government consultants/experts who are bound by appropriate non-disclosure requirements. Non-Government technical consultants/experts will not have access to proposals that are labeled by their offerors as "Government Only". Historically Black Colleges and Universities (HBCUs) and Minority Institutions (MIs) are encouraged to submit proposals and join others in submitting proposals; however, no portion of this BAA will be set aside for HBCU/ MI participation due to the impracticality of reserving discrete or severable areas of research in Optical Arbitrary Waveform Generation.

Proposal Evaluation

Evaluation of each proposal will be accomplished through a technical review using the following criteria, listed in descending order of importance: 1. Overall scientific and technical merit of the proposal. 2. Value to defense. 3. Capability of the personnel and facilities to perform the proposed effort. 4. Cost realism.

GENERAL INFORMATION:

This notice, in conjunction with the BAA 05-11 Proposer Information Pamphlet, constitutes the total BAA. No additional information is available, nor will a formal RFP or other solicitation regarding this announcement be issued. Requests for the same will be disregarded. In all correspondence, reference BAA05-11.

Address for Submission of Full Proposals:
DARPA/DSO, ATTN: BAA05-11, 3701 North Fairfax Drive, Arlington, VA 22203-1714.

Web address for Full Proposal Submission: http://www.sainc.com/dso0511/.

Guidance for Classified Information and Data: The Government anticipates that proposals submitted under a BAA will be unclassified. In the event that a proposer chooses to submit a classified proposal, the following information is applicable. Security Classification guidance on DD Form 254 will not be provided at this time since DARPA is soliciting ideas only. After reviewing the incoming proposals, if a determination is made that the award instrument may result in access to classified information, a DD Form 254 will be issued and attached as part of the award. Proposers choosing to submit a classified proposal must first receive permission from the Original Classification Authority to use their information in applying to this BAA. An applicable classification guide should be submitted to ensure that the proposal is protected appropriately. For Instructions on Submitting Classified White Papers or Full Proposals Contact: Robert Copeland, Director, Security & Intelligence Directorate (703) 526-6631. In all correspondence, reference BAA05-11.

Points of Contact:
Dr. John R. Lowell, DARPA/DSO; Phone (571) 218-4685; Fax: (703) 807-4962;
Dr. Jagdeep Shah, DARPA/MTO; Phone: (703) 696-2253; Fax: (703) 696-2206.

This announcement and the Proposer Information Pamphlet may be retrieved at URL http://www.darpa.mil/ in the solicitations area.

Administrative Point of Contact
Lisa Roberson, Phone (571) 218-4531